AD NUMBER

AD908737

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 01 NOV 1972. Other requests shall be referred to Range Measurements Laboratory, Air Force Eastern Test Range, Patrick AFB, FL 32925.

AUTHORITY

DARPA ltr dtd 13 Sep 1973

SB (1)

AD908737

DDC FILE COPY

(19)

(18) AFETR TR-73-DL-2

(6) MEASUREMENTS OF THE BEAM AND POINT SPREAD FUNCTIONS OF SEA WATER,

(11) 1 NOV [redacted] 72

Prepared by

(10) Lawrence [redacted] E. Mertens [redacted] David L. Phillips,

RCA Service Co.

(15) F08606-73-C-0014

DISTRIBUTION B

"TEST + EVALUATION"

Distribution limited to U. S. Government Agencies only. [redacted]. Other requests for this document must be referred to the Range Measurements Laboratory, Air Force Eastern Test Range, Patrick Air Force Base, Florida. 32925

9 APR 1973

(9) Summary rept.,

(12) 35p.

Range Measurements Laboratory
Air Force Eastern Test Range
Patrick Air Force Base, Florida

299250

NOTICES

"TEST + EVALUATION" APR 1973

Distribution limited to U. S. Government Agencies only. [redacted] Other requests for this document must be referred to the Range Measurements Laboratory, Air Force Eastern Test Range, Patrick Air Force Base, Florida. 32925

This document has been reviewed and approved by:

Glenn H. Micklow

G. H. MICKLOW, Program Engineer
Range Measurements Laboratory

Harold D. Newby

H. D. NEWBY, Program Manager
Range Measurements Laboratory

W. H. Manning Jr.

W. H. MANNING, JR., Director
Range Measurements Laboratory

When this document has served its intended purpose, it should be destroyed. Do not return this document to the Defense Documentation Center nor to the Range Measurements Laboratory.

MEASUREMENTS OF THE BEAM AND POINT SPREAD FUNCTIONS OF SEA WATER

1 NOVEMBER 1972

Prepared by

L. E. MERTENS, Chief Scientist
Deep Look Project
RCA Service Co.
Patrick AFB, Florida

D. L. PHILLIPS, Systems Analyst
Deep Look Project
RCA Service Co.
Patrick AFB, Florida

FOREWORD

This report was prepared by L. E. Mertens and D. L. Phillips, RCA Service Co., Deep Look Project, under Contract #F08606-73-C-0014.

A great deal of effort has been expended on this program to correlate theoretical calculations with in situ experimental data. Theoretical and experimental investigations were repeated and refined to the point where the confidence level in theoretical calculations is acceptable for determining the actual performance of any proposed undersea optical system.

This report summarizes the long path optical data measured in coastal and oceanic water in the Bahamas. Other Project Deep Look reports show how this data can be used to compute imaging system performance.

It is our hope that the data contained in this report will allow the number of prototypes constructed during system development to be reduced by using analytical techniques.

Publication of this report does not constitute Air Force Approval of the reports findings or conclusions. It is published only for the exchange and stimulation of ideas.

Glenn H. Mucklow

G. H. MUCKLOW, Program Engineer
Range Measurements Laboratory

ABSTRACT

This report presents the first *in situ* sea water measurements of the Beam Spread Function (BSF) and Point Spread Function (PSF). Furthermore, these measurements are valid to much smaller angles than those previously published and should be of value in imaging system analysis. Measurements are presented for sea water ranging from clear coastal to maximum clarity deep oceanic; over an angular range from less than ~~[illegible]~~ .0001 radians to 180 deg and for propagation ranges up to nine attenuation lengths.

CONTENTS

I. INTRODUCTION

The Beam Spread Function, BSF (R,θ,ϕ) maps the irradiance field at the range R about a collimated light source. The Point Spread Function, PSF (R,θ,ϕ) describes the radiance distribution produced by a small lambertian point source which is observed from a point at the range R. These two functions are important basic optical parameters for predicting image propagation in sea water. In fact, most of the other optical parameters which have been used to describe the propagation of light in water can be derived from either BSF or PSF measurements. For example, the volume attenuation coefficient, α, can be easily determined from the logarithmic slope of the on axis BSF or PSF as a function of range. The volume absorption coefficient, a, can be estimated from the loss in total light energy as a function of range. The total light loss can be determined by integrating the BSF or PSF over the entire solid angle. From these α and a coefficients, the volume scattering coefficient, s, can be computed using the simple relationship α-a=s. For small angles, the BSF can be used to compute the Volume Scattering Function, VSF,* which is commonly used to describe the angular scattering properties of water. The VSF in turn can be related to the size distribution and refractive index of the particles in sea water. The modulation transfer function (MTF) of the water path can be determined by taking the two-dimensional Fourier transform of the BSF or PSF.

The BSF and PSF of sea water can be measured conveniently and accurately

*L. E. Mertens and D. L. Phillips
Deep Look Report "Measurements of the Volume Scattering Function of Sea Water", 7 March 1972, TR#334.

with instrumentation developed on the Deep Look Program. Unlike the more conventional measurements, these functions are measured over long ranges - usually comparable to the desired system operational ranges. Small measurement errors do not increase when this long path data is used in making system predictions and computations. Note that conventional parameters are usually measured over short one meter paths and any measurement errors increase exponentially when scaling or propagating to the longer operational paths. For these reasons the BSF and PSF have been selected in the Deep Look Program as the basic input data to describe the transmission properties of sea water.

BSF and PSF data presented in this report are the first in situ measurements for sea water. Furthermore these measurements are valid to much smaller angles than those previously published and should thus be of value in imaging system analysis. Measurements are presented here for sea water ranging from clear coastal to maximum clarity deep oceanic; over an angular range from less than 10^{-4} radians up to 180° and for propagation ranges up to nine attenuation lengths.

II. THE BEAM SPREAD FUNCTION - BSF

The BSF will be defined as the irradiance at each point on the surface of a sphere of radius R having its origin at the source of a collimated beam of light (of negligibly small cross-section). As can be seen in Figure 1, the BSF is a function of R, θ, ϕ; the spherical coordinates of the point on the surface of the sphere.

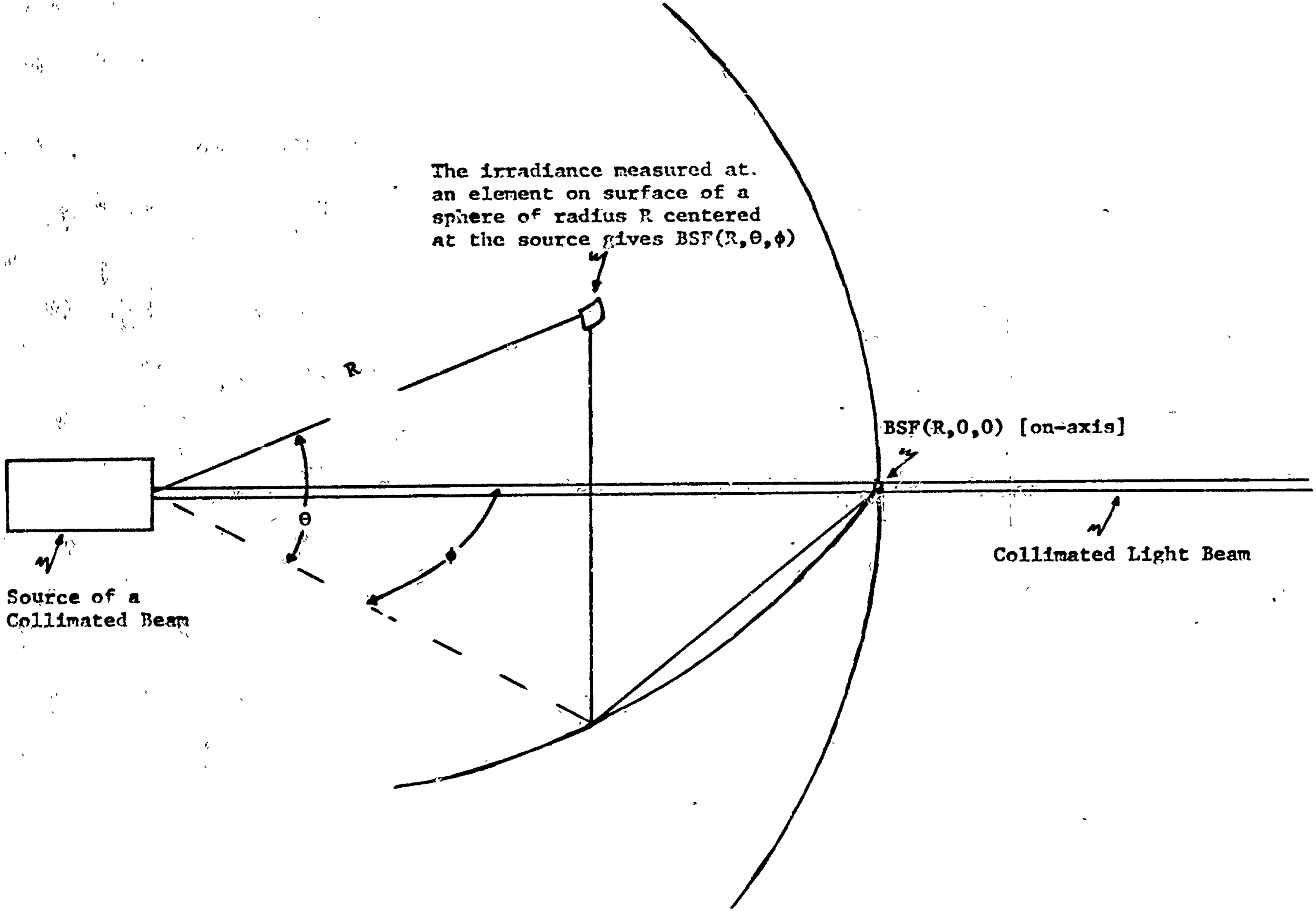


FIGURE 1 BSF DEFINITION

The BSF is also a function of several other parameters that are not geometry dependent. The output power of the transmitter is one of these parameters. In order to eliminate the influence of transmitter power, it is conventional to normalize the BSF with respect to the transmitter power. When this is done the BSF has units of $(\text{meters})^{-2}$. In this report we always use this form of the normalized BSF unless specifically stated otherwise*. The BSF is, of course, a function of the wavelength of light used. Since the Deep Look Program is principally concerned with very long range imaging systems, most measurements have been made near the optimum transmission wavelength of water (i.e., 480 nm).

At large angles off axis, the BSF is affected by the transmitter polarization. Therefore, measurements have been made with both horizontal and vertical linearly polarized sources.

The absorption and scattering properties of the water (and its dissolved and suspended materials) have a major effect on the shape of the BSF. For the large angle region, the BSF's for many types of water appear to be quite similar if measured at the same normalized range (i.e., same number of attenuation lengths, αR) and the α/a ratios for the various types of water are approximately the same. The situation, however is quite different in the small angle region where temperature and

*The BSF can be made completely non-dimensional by multiplying by R^2. This additional normalization is convenient for many purposes and has been used by W. Wells.

salinity inhomogeneities as well as the size and refractive index distribution of the particulate matter become very important.* Most conventional instrumentation used to measure the optical properties of water cannot detect these effects and, hence, could lead to serious errors in imaging system analysis where small angle scattering is very significant.

* *The simple definition of the BSF which is presented above is not completely adequate for a detailed study of the propagation of light in water. For example, the size (diameter) of the source beam relative to the scatterers (i.e., molecules, suspended particles, and turbulences) is important in diffraction phenomena. The idealized "point" collimated source used in the BSF definition is physically unrealizable and measurements have actually been made with laser beams having diameters on the order of 1 cm and divergences less than 10^{-3} radians. The actual source beam is thus considerably larger than the suspended particles and molecules and it's exact dimensions are not critical for our BSF measurements (which are normally for angles greater than 10^{-3} radians). The dominant turbulence scales, however, are comparable to or greater than the actual source beam diameter. When scattering from such turbulences becomes important, greater precision must be used in defining and measuring the BSF.*

III. THE POINT SPREAD FUNCTION - PSF

The geometry used for defining the PSF is shown in Figure 2. The PSF for the range, R, is defined here as the radiance distribution arriving at a point at range R from a small lambertian point source.* For a particular range the value of the PSF will vary with the angle of arrival of the light rays.

The PSF will be normalized with respect to the radiant intensity of the light source. Thus it also has units of $(\text{meters})^{-2}$ the same as for the previously defined normalized BSF. In this report we always use the normalized PSF unless specifically stated otherwise.

Just as in the case of the BSF, the PSF is a function of range, the polar angles θ and ϕ, source wavelength, and the water's optical properties.

IV. RELATIONSHIP BETWEEN BSF AND PSF

The discussions in the preceding sections make it apparent that the normalized BSF and PSF are very similar. They both have the same units and yield the same basic optical parameters. Furthermore,

* *Note that PSF is more conventionally defined as the irradiance distribution in the image plane of the system.*

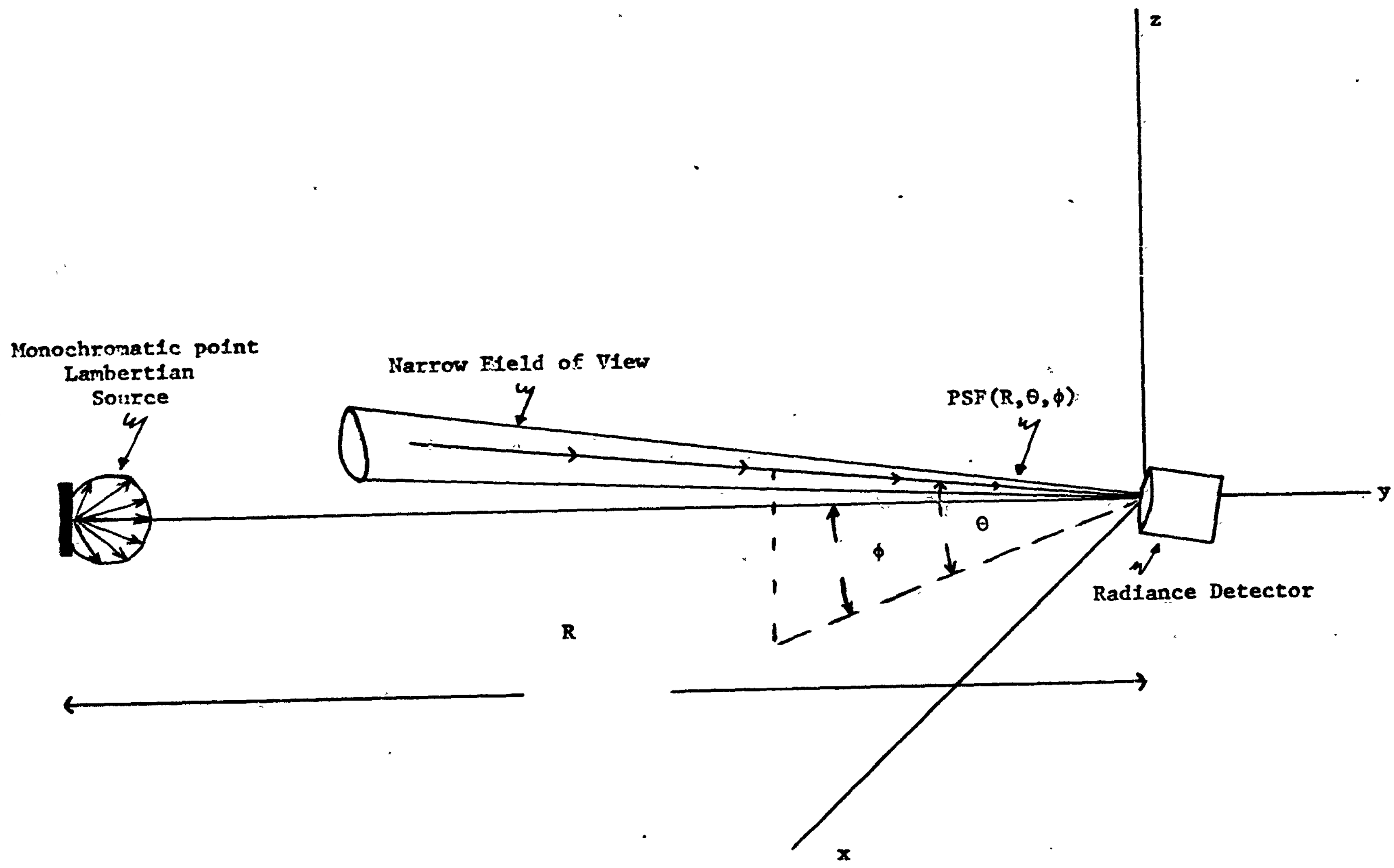


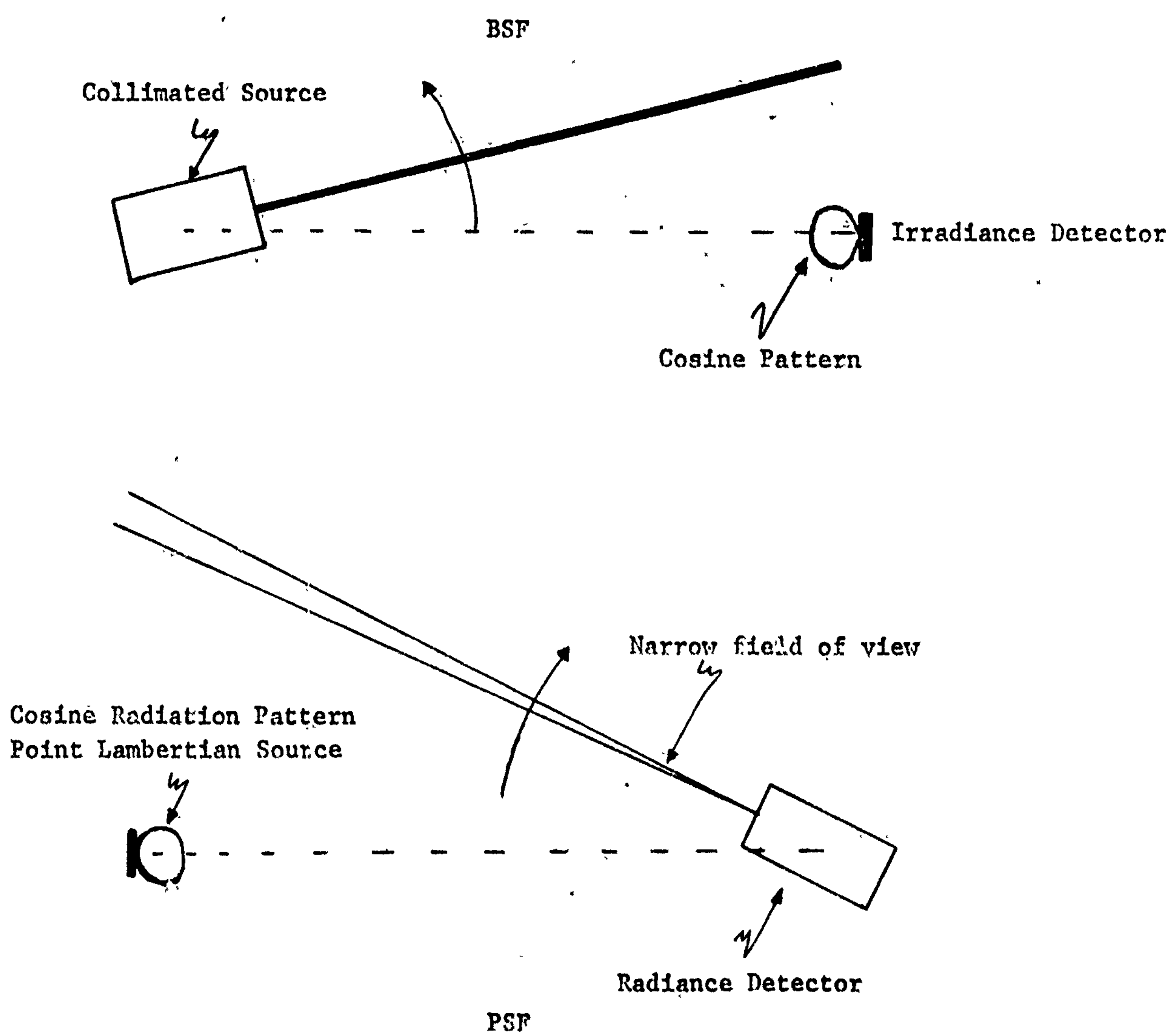
FIGURE 2 PSF DEFINITION

the measurement curves turn out to be quite similar in shape and magnitude. This similarity leads us to question whether the BSF and PSF might be identical in theory.

The BSF and PSF can be thought of as transfer functions between specific transmitter and receiver configurations. A brief review of the methods of measurement of the BSF and PSF indicate a certain reciprocity which is more evident by reference to Figure 3. In the case of the BSF we have a narrow (collimated) transmitter beam and a wide angle (cosine pattern) receiver. In the PSF case we have a cosine transmitter radiation pattern and a narrow beam receiver. The BSF and PSF thus represent a set of "reciprocal" measurements in which the source and receiver are interchanged. A very general form of the "reciprocity theorem" indicates that the transfer relations will be the same for both cases provided that the medium meets certain conditions such as linearity. In our measurements, exact reciprocity does not exist because 1) the laser transmitter was linearly polarized while the radiance measuring instrument was normally used without polarizers and 2) the laser transmitter had a very narrow and collimated beam while the radiance measurements used a wider aperture and slightly diverging beam (i.e., field of view). It will be shown later that the polarization differences are important mainly at very large angles and the narrow beam characteristics will only affect the very small angle measurements. Thus we would expect (and actually find) the normalized BSF's and PSF's to be essentially the same over most of our measurement range.

FIGURE 3

Reciprocity of BSF and PSF



V. FIELD MEASUREMENT TECHNIQUES

BSF and PSF measurements on the Deep Look Project have been made at two locations near Andros Island, Bahamas. One is in shallow coastal water behind High Cay and the other is in deep oceanic water (2000m deep) in the Tongue of The Ocean, TOTO. At High Cay all of the BSF and PSF instrumentation is mounted on pedestals which set on the sea floor. In the TOTO, the instrumentation is mounted on a 20 meter long optical bench which is suspended below the instrumentated barge.

The light source for most of the BSF measurements has been a CW Argon laser which has five major emission lines in the 457.9 to 514.5nm wavelength region. Individual spectral lines can be selected and optics are available to collimate the beam. The irradiance detector is a Cintra radiometer with a diffuser to give approximately a 160° field of view. This detector is normally operated unpolarized, but a linear polarizer can be added when desired. The laser, of course, is linearly polarized.

The optical output power of the laser source is measured during the test by moving the Cintra detector as close as possible to the laser port. This power level is then maintained with the aid of a power monitor located within the laser housing.

Our normal test procedure is to tune the laser to the desired wavelength, collimate the beam and adjust the output power of the laser. With the transmitter set-up and operating, the irradiance field about the source is measured. This could be done by moving the Cintra detector at a fixed range R, over the surface of the sphere, centered at the source; however, it is usually more convenient to use a fixed detector and rotate the laser housing. Since the BSF appears symmetrical about the beam axis for most regions of interest it is necessary to scan the beam (from 0° to 180°) in one dimension only. When there is reason to believe that the scattering may be significantly asymmetrical,* scans in several planes can be measured to define the irradiance field.

The BSF has been measured for ranges from less than one to approximately nine attenuation lengths and for angles as small as a few hundredths of a milliradian. In order to investigate any asymmetry due to source polarization two orthogonal scans of the laser beam were used to measure the BSF. One scan is along the plane parallel to the laser polarization and the other along the plane perpendicular to the laser polarization. The BSF has also been measured as a function of wavelength over the Argon laser band. Water properties are monitored during the tests using other Deep Look instrumentation.

The PSF has been measured using both electronic and photographic sensors in shallow water at High Cay and by photographic techniques

*For example, asymmetry occurs at large angles with polarized light sources.

only in the deep water of the TOTO. The majority of the High Cay PSF measurements were made with a CW Argon laser illuminating a small diffuser as the point lambertian source. The radiance detector was a modified Pritchard photometer (air focal length 84 inches, f/15 lens and in-water F.O.V. 1.08 milliradian). Linear polarizers can be inserted in the photometer if desired.

For the electronic technique the radiant intensity of the point source is measured during the test and maintained using the laser power monitor. The wavelength desired is selected at the laser. The radiance field arriving at the narrow field of view detector at the range R is measured by rotating the photometer from 0° to 90° (i.e., in Figure 2, $\theta = 0$, ϕ varies from 0° to 90°). The PSF has been measured using this technique at High Cay for ranges to approximately nine attenuation lengths.

The photographic technique involves photographing a small diameter "point" lambertian source at various ranges from the camera. The film is developed and the density produced by the scattered light is read on a microdensitometer. Density readings are converted to energy and appropriately scaled to yield the PSF. Details of the point source differed for the various tests.

The point source for the deep water tests in November 1971 used a 250 watt Quartz Iodide lamp in a light-tight housing. A 1mm or a 10mm clear aperture in the housing could be selected to define the "point" source. Two sheets of diffuser with a Wratten 45A filter between them was placed between the lamp and the defining aperture. This point source assembly was mounted on the long bench at approximately 19m from the automatic camera (Nikon 250 exposure with F = 800mm, f/3.8 lens). The camera focus range can be remotely varied in small steps to bracket an object distance change of 0.5 meter so as to insure at least one photograph in sharp focus despite anticipated thermal expansion and refractive index variations. Photographs were recorded at several depths for both apertures and a range of exposure times to insure optimum film density for all scattering angles within the field of view. The developed film was previewed with a microscope to identify the frames with sharpest focus and optimum density range. The selected frames were scanned on a microdensitometer and then converted into energy per unit area in the film plane as a function of the angle from the center of the image. The energies recieved were then normalized by the exposure time, camera parameters, and source intensity to produce the PSF.

VI. TEST RESULTS

The in situ measurements discussed in this section were conducted in 1971 as a portion of the Deep Look Project.

Figures 4 and 5 show the affect of range on BSF and PSF respectively. These data were measured for clear coastal water at High Cay during March and June 1971. Both sets of data were measured for a wavelength of 488nm and the BSF detector was scanned in a plane perpendicular to the polarization of the laser.

FIGURE 4

Beam Spread Function For Clear Coastal Water

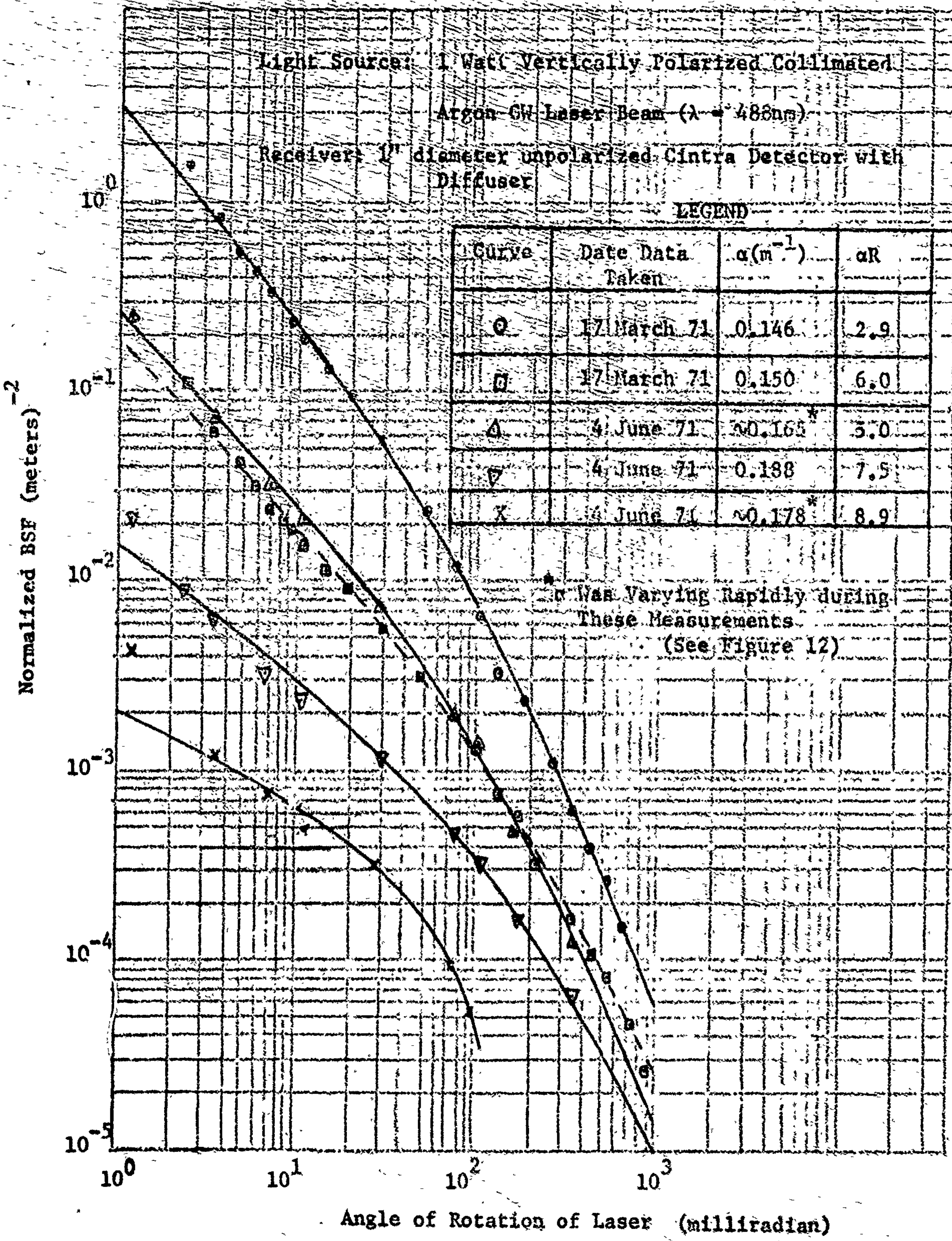
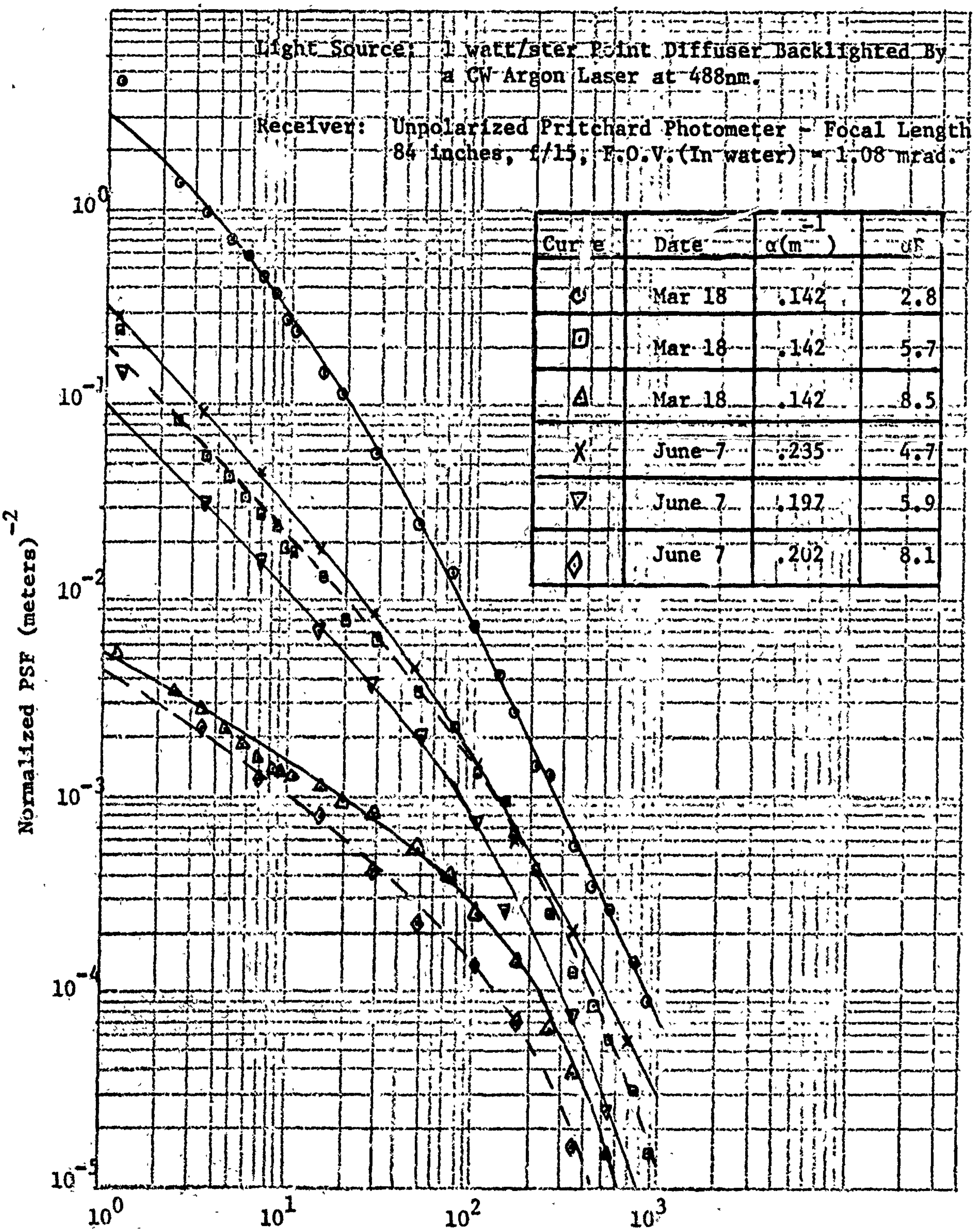


FIGURE 5

Point Spread Function for Clear Coastal Water



For the small angle region the slope of these curves gets less as range increases. Since these data plot as nearly straight lines on log-log paper we see that the BSF and PSF data can be approximated over a reasonable range of angles θ by the expression $K\theta^{-n}$ where K and n are functions of the range.

Figure 6 is another useful presentation of the Figure 5 data. Here the value of the PSF is plotted versus range for three particular angles. The slope of these curves is approximately equal to α, the volume attenuation coefficient, for small angles off axis. The slope (or effective attenuation coefficient) is less than α for larger angles. This explains why broad or diffuse light sources propagate with less attenuation than α.

RELATIONSHIP OF BSF AND PSF

Comparison of the data shown in Figures 4 and 5 shows that the normalized BSF and PSF are nearly identical. BSF and PSF curves for the same attenuation length show absolute agreement within 30%. Table 1 shows the value of the ratio of the PSF to the BSF measured for an angle of ten milliradians. The average value of this ratio for nine observations differs from unity by less than 3%. Considering the accuracy of the measurements it can be said that our data supports the hypothesis that the normalized BSF and PSF functions are identical.

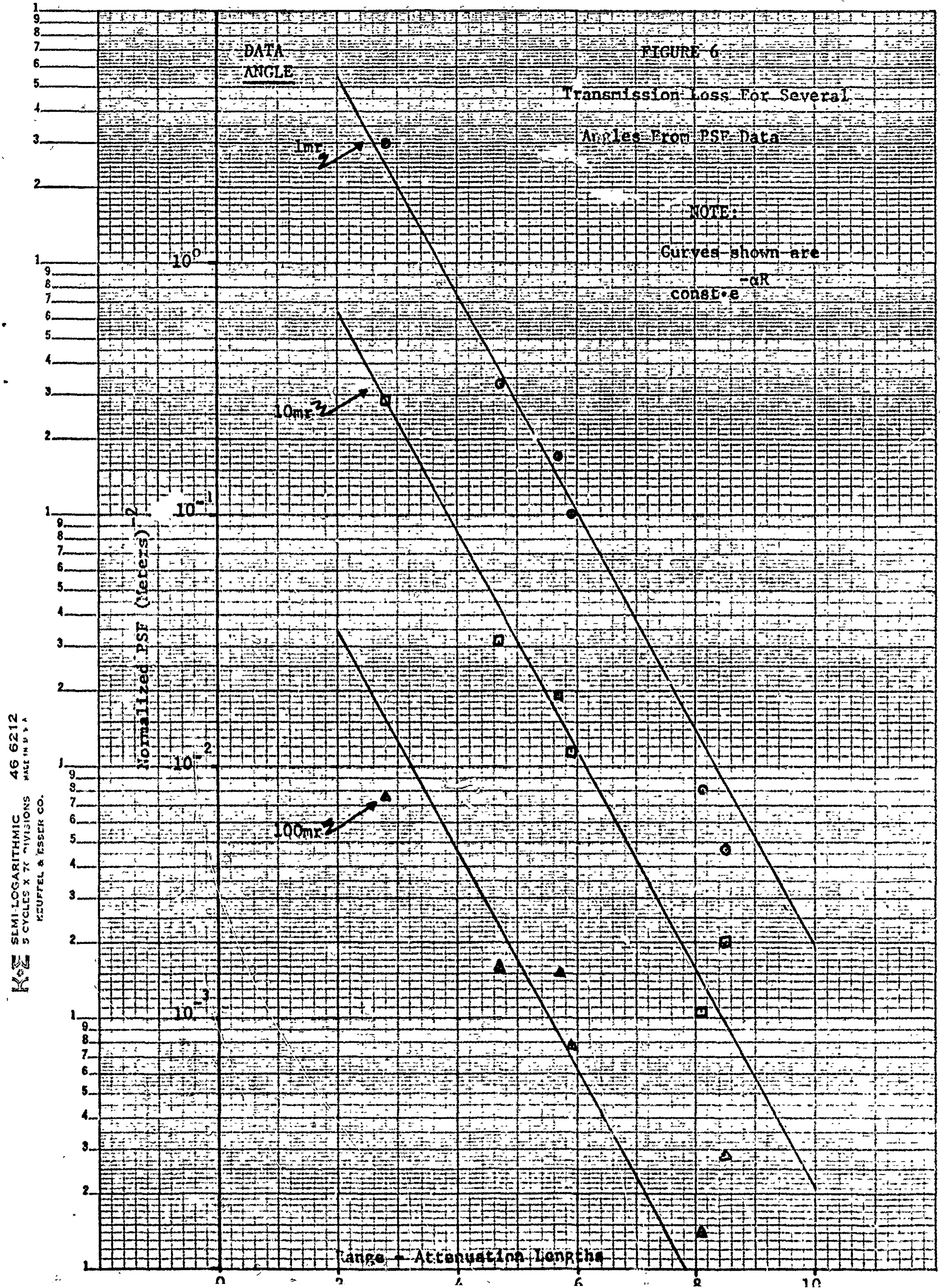

DATA
ANGLE
FIGURE 6
Transmission Loss For Several
Angles From PSF Data
NOTE:
Curves shown are
const·e^-αR
1mr
10mr
100mr
Normalized PSF (Meters)^-2
Range - Attenuating Lengths
SEMI-LOGARITHMIC 46 6212
5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.

TABLE 1

Ratio of Normalized PSF to the Normalized BSF at 0.01 radians

Date	Range in Attenuation Length	Laser Polarization For BSF	PSF / BSF Ratio
March 1971	2.8	Vertical	1.18
March 1971	5.6	Vertical	1.02
June 1971	5.0	Vertical	0.99
June 1971	7.5	Vertical	0.86
June 1971	8.9	Vertical	0.96
June 1971	5.0	Horizontal	1.23
June 1971	7.5	Horizontal	0.78
June 1971	8.9	Horizontal	0.76
		Average Ratio	0.97

DEPENDENCE ON TYPE OF WATER

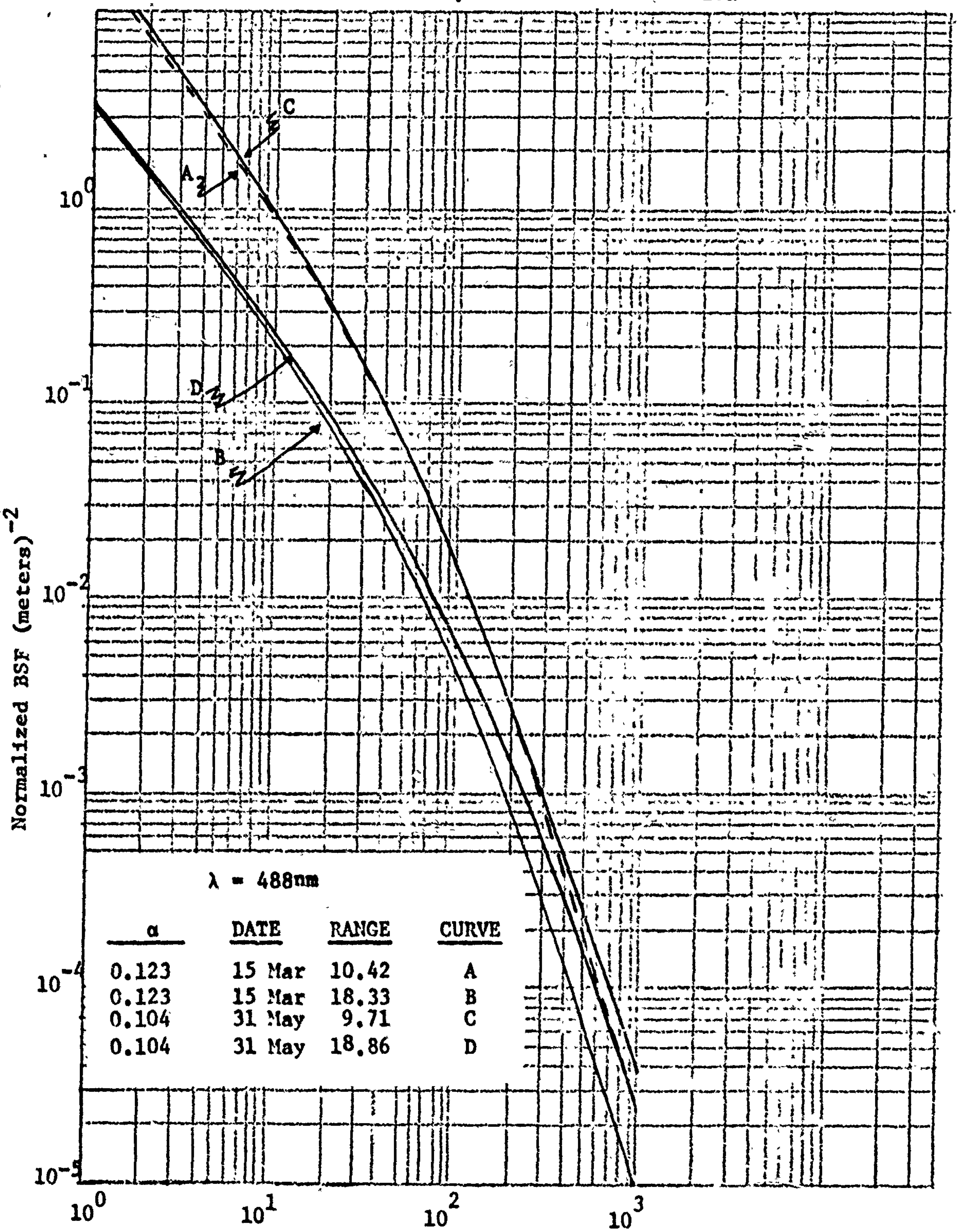
The BSF measured for surface oceanic water in the TOTO is shown in Figure 7. It is interesting to compare this data with that of clear coastal water (Figure 4). Comparison of the curves should be made for equivalent numbers of attenuation lengths rather than equivalent physical ranges. This procedure adjusts for the large difference in clarity between the different waters. Unfortunately, we are limited to 20 meter paths in the deep water due to the mechanical problems of deploying longer optical benches at sea. Also the normalized ranges (in terms of attenuation lengths) are not exactly equivalent for both Figures. However, comparison of the shorter range spread functions indicates that they are very similar in shape and magnitude despite differences in the water.

The affect of water parameters on the PSF at a given range can be seen in the photographic data we collected in November 1971. The non-normalized PSF for depths of 30 meters and 217 meters in the TOTO are shown in Figures 8 and 9. Our data is the first measured in the deep clear ocean. As can be seen, our smallest angle measured was approximately 4 X 10^{-5} radians. The PSF's shown are not normalized. The curve shape (for the 30 meter depth data) agrees very well with the data in Figure 5.

The curves shown in Figures 8 and 9 have been corrected for lens flare determined by an in-air calibration of the camera.

FIGURE 7

March and May Surface TOTO BSF Data



Angle of Rotation of Laser (milliradians)

FIGURE 8

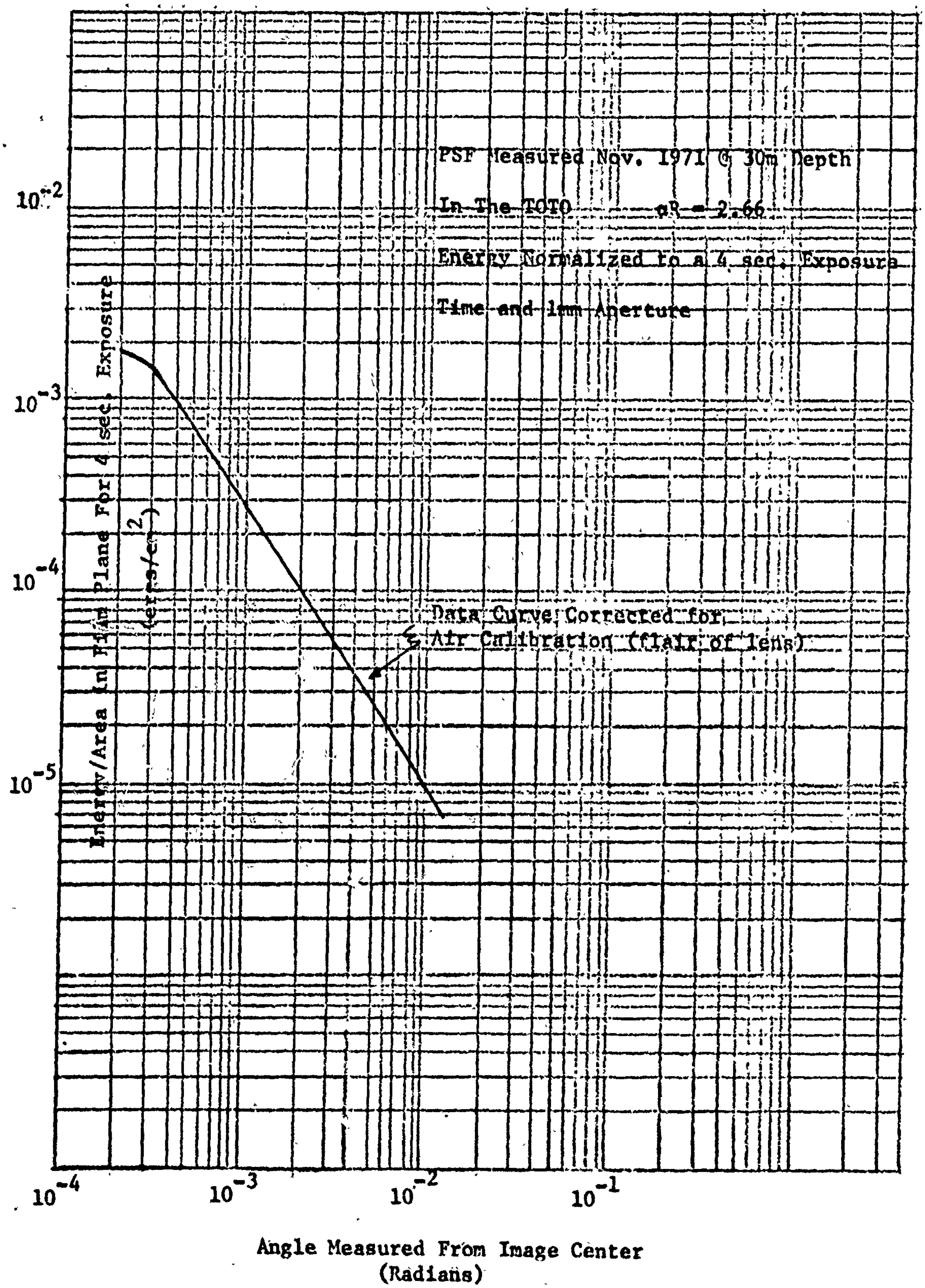
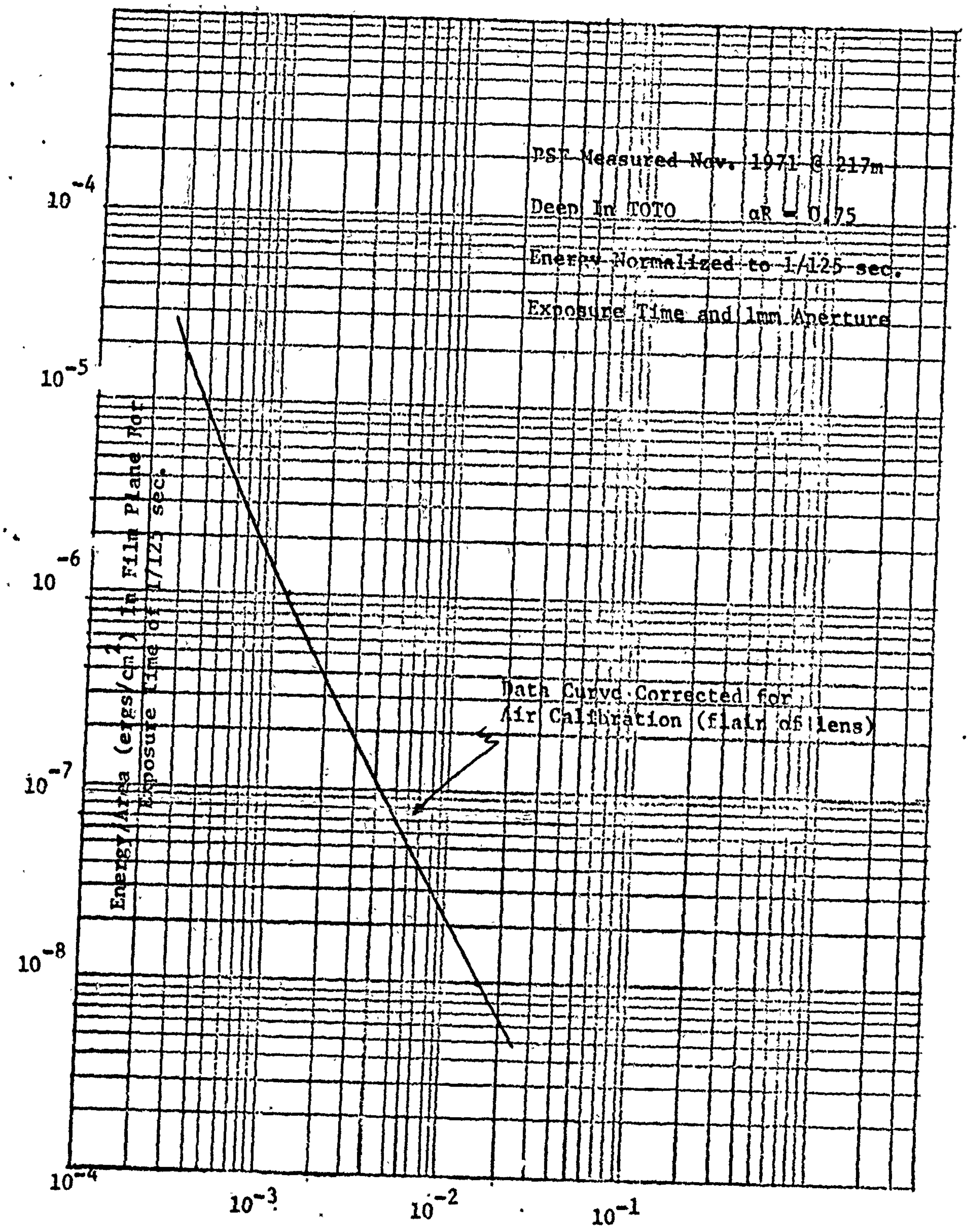

PSF Measured Nov. 1971 @ 30m Depth
In The TOTO αR = 2.66
Energy Normalized to a 4 sec. Exposure
Time and 1mm Aperture
Data Curve Corrected for
Air Calibration (flair of lens)
Energy/Area in Film Plane For 4 sec. Exposure (ergs/cm²)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
Angle Measured From Image Center
(Radians)

FIGURE 9



Angle Measured From Center of Image
(Radians)

WAVELENGTH DEPENDENCE

The BSF and PSF will vary with the wavelength of light employed due to the change in both the absorption and scattering with wavelength. Figure 10 shows the BSF(Θ) for approximately 7 attenuation lengths for wavelengths of 488nm and 515nm. For small angles the scattering is about the same at both wavelengths but for large angles the scattered light is significantly less at the longer wavelength.

POLARIZATION DEPENDENCE

The dependence of the BSF on transmitter polarization (relative to the plane of measurement) is shown in Figure 11. These data were collected 31 May 1971 in the TCTO with an unpolarized receiver for two transmitter to receiver ranges. At each range data were collected with the detector scan perpendicular to the laser polarization (transmitter polarization vertical) and detector scan parallel to the laser polarization (transmitter polarization horizontal). The transmitter polarization makes no difference in the BSF for angles less than approximately 0.3 radians. Beyond 0.3 radian the received scattered energy is less for the transmitter polarization horizontal (i.e., in the plane of measurement). As a result, horizontal polarization is preferred for imaging systems since it produces slightly less backscatter and has no other disadvantages. Note carefully that these measurements do not use a polarized receiver and are not directly related to the use of cross polarizers for backscatter reduction.

FIGURE 10

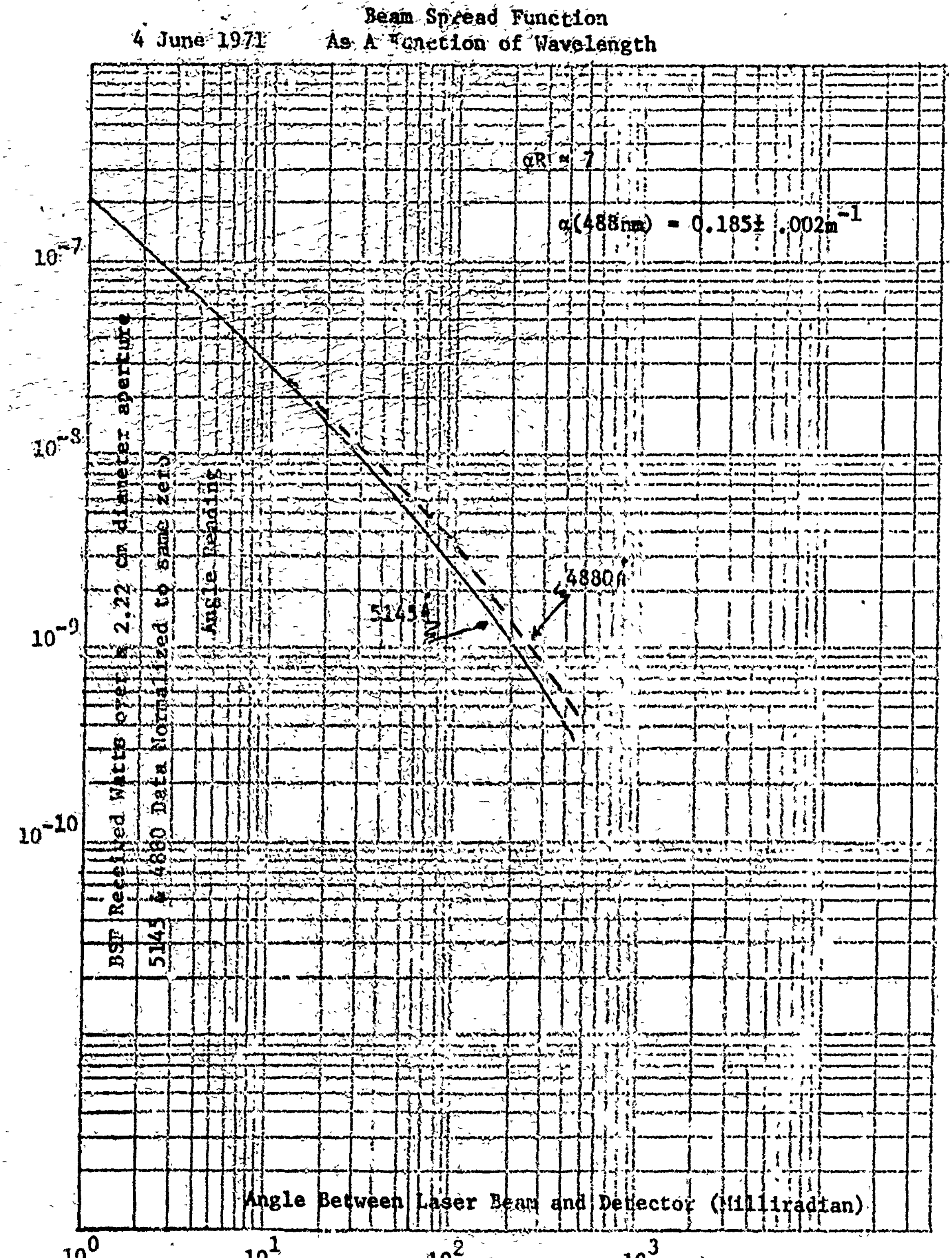
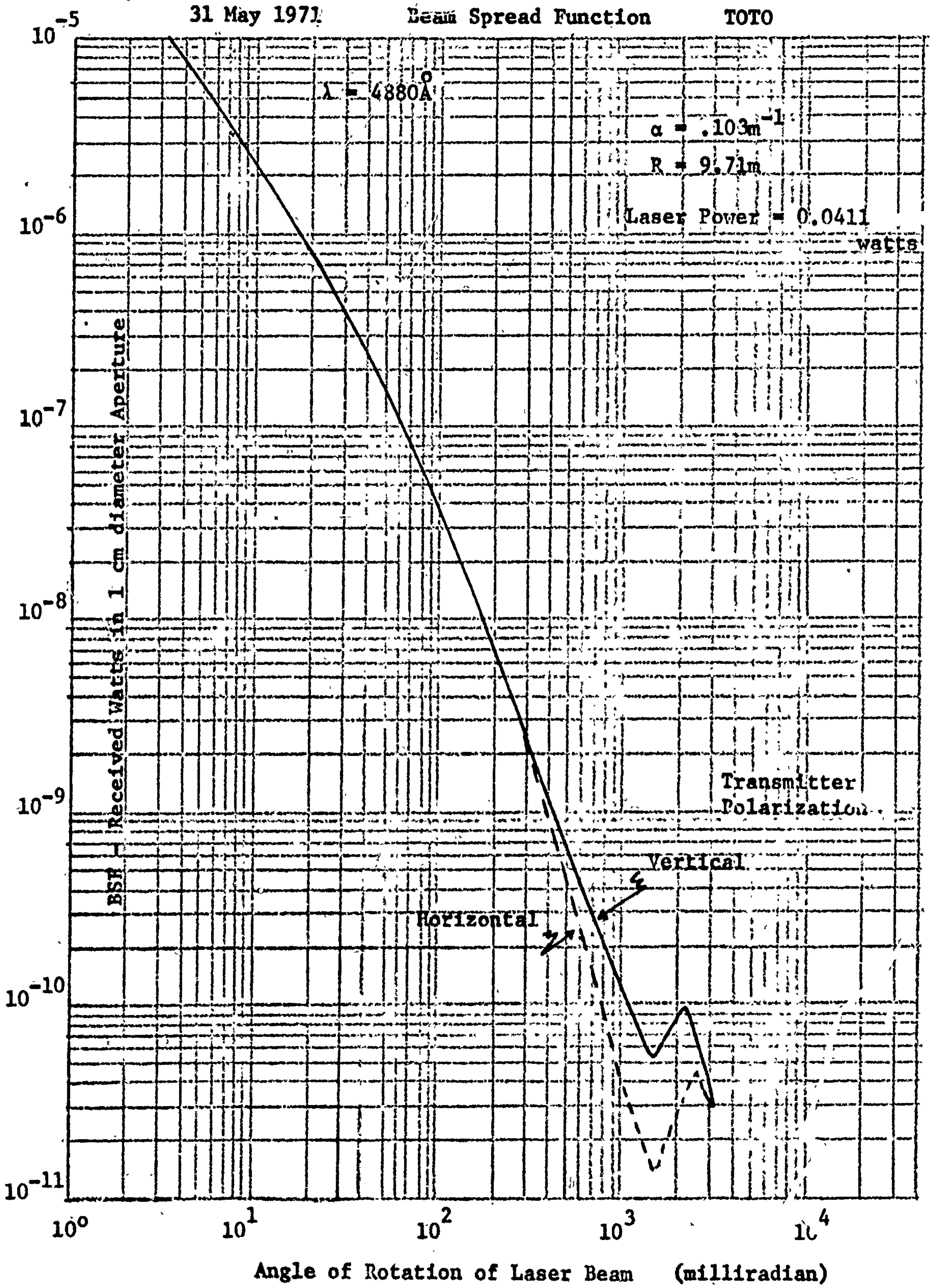

4 June 1971
Beam Spread Function
As A Function of Wavelength
αR ≈ 7
α(488nm) = 0.185± .002m⁻¹
4880Å
5145Å
BSF Received Watts over a 2.22 cm diameter aperture
5145 & 4880 Data Normalized to same zero
Angle Bending
Angle Between Laser Beam and Detector (Milliradian)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁰
10¹
10²
10³

FIGURE 11


31 May 1971
Beam Spread Function
TOTO
λ = 4880Å
α = .103m⁻¹
R = 9.71m
Laser Power = 0.0411 watts
Transmitter Polarization
Vertical
Horizontal
BSR - Received Watts in 1 cm diameter Aperture
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^0
10^1
10^2
10^3
10^4
Angle of Rotation of Laser Beam (milliradian)

VII. DATA ACCURACY

In conclusion some general remarks should be made concerning the accuracy and quality of the data presented in the report. The data appear repeatable and have relatively low random noise as can be seen by examining the fluctuations of the actual data points about the smoothed curves. In addition, a theory developed by W. Wells* shows how the PSF (or BSF) for a given range is related to that for another range. Analysis of the experimental data by Wells and ourselves showed that it is consistent with this theory.

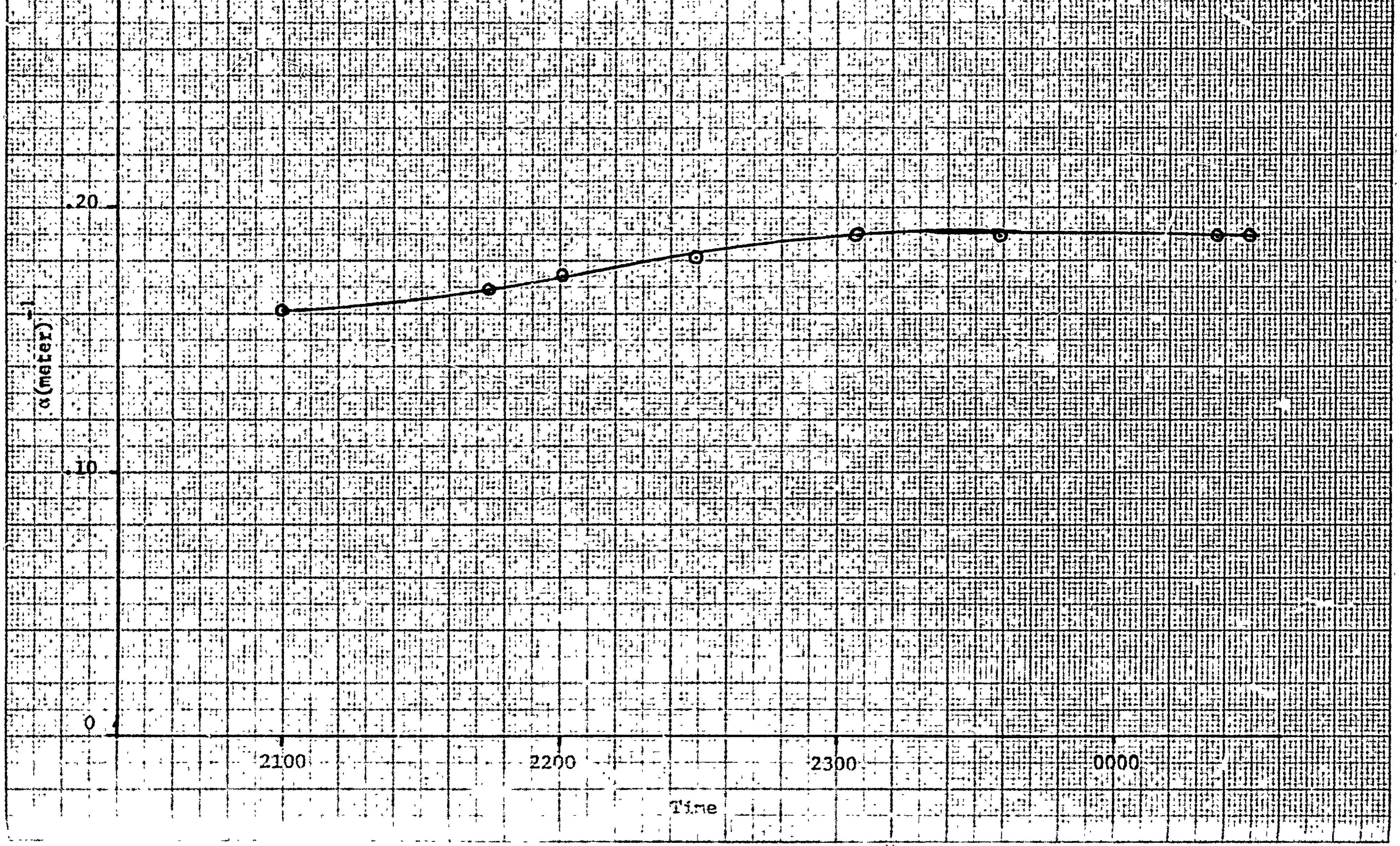
It is well to note, however, some of the sources of error in the measurements. The data collected at High Cay has three sources of environmentally caused error sources. One is the variability of α in the shallow coastal water. The α varies rapidly and by large amounts with changes in wind conditions and tides. The change in α that occurred during the June BSF (data shown in Figure 4) is shown in Figure 12. Here α increased steadily for two hours before it became stable. Variable α can cause data inconsistencies within one test (or even one run through all angles at one range). It can also result in the wrong value of αR being associated with a particular data run. It appears that this may cause a problem in some of the Figure 4 and 5 data where it was not practical to monitor α continuously during the spread function measurements.

*Wells, W. H., "Loss of Resolution in Water as a Result of Multiple Small Angle Scattering", J. Opt. Soc. Am., 59, June 1969.

K+E 10 X 10 TO THE CENTIMETER 46 1512
18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

FIGURE 12

α Determined from 4 June '71 BSE Data



A second problem at High Cay is plankton accumulation around the light source. Working at night with very bright light sources sometimes attracts plankton. This, of course, causes local increase in the attenuation and scattering of the light. A diver near the light source has been used to monitor this problem and if plankton begins to accumulate, the light is turned off until the plankton dissipates. Measurements are taken as fast as possible to minimize both α changes and plankton build-up.

The third problem involves the measurement geometry. High Cay measurements are conducted in water that is approximately 5 meters deep. The ocean floor is coarse white sand. Thus, at the larger angles the BSF or PSF detectors will see diffuse scattering from the ocean floor and reflections from the ocean surface. This extra scattering causes the BSF and PSF curves to be too large for greater angles.

All of the above problems, except scattering off of the ocean floor, can affect measurements in the TOTO. However, due to the more stable water environment of the deep ocean and slight motion of the measuring platform, they do not seem to result in significant data errors in the TOTO.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) RANGE MEASUREMENTS LABORATORY AIR FORCE EASTERN TEST RANGE PATRICK AFB, FLORIDA 32925	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

MEASUREMENTS OF THE BEAM AND POINT SPREAD FUNCTIONS OF SEA WATER

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

SUMMARY

5. AUTHOR(S) (First name, middle initial, last name)

LAWRENCE E. MERTENS, RCA SERVICE CO.
DAVID L. PHILLIPS, RCA SERVICE CO.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
1 NOVEMBER 1972	34	2

8a. CONTRACT OR GRANT NO. F08606-73-C-0014 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) ETR-TR-73-DL-2 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT [redacted]

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	ARPA, ADVANCED SENSORS

13. ABSTRACT

THIS REPORT PRESENTS THE FIRST IN SITU SEA WATER MEASUREMENTS OF THE BEAM SPREAD FUNCTION, BSF AND POINT SPREAD FUNCTION, PSF. FURTHERMORE, THESE MEASUREMENTS ARE VALID TO MUCH SMALLER ANGLES THAN THOSE PREVIOUSLY PUBLISHED AND SHOULD BE OF VALUE IN IMAGING SYSTEM ANALYSIS. MEASUREMENTS ARE PRESENTED FOR SEA WATER RANGING FROM CLEAR COASTAL TO MAXIMUM CLARITY DEEP OCEANIC; OVER AN ANGULAR RANGE FROM LESS THAN 10^{-4} RADIANS TO 180° AND FOR PROPAGATION RANGES UP TO NINE ATTENUATION LENGTHS.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT